Progress on Grating Fabrication

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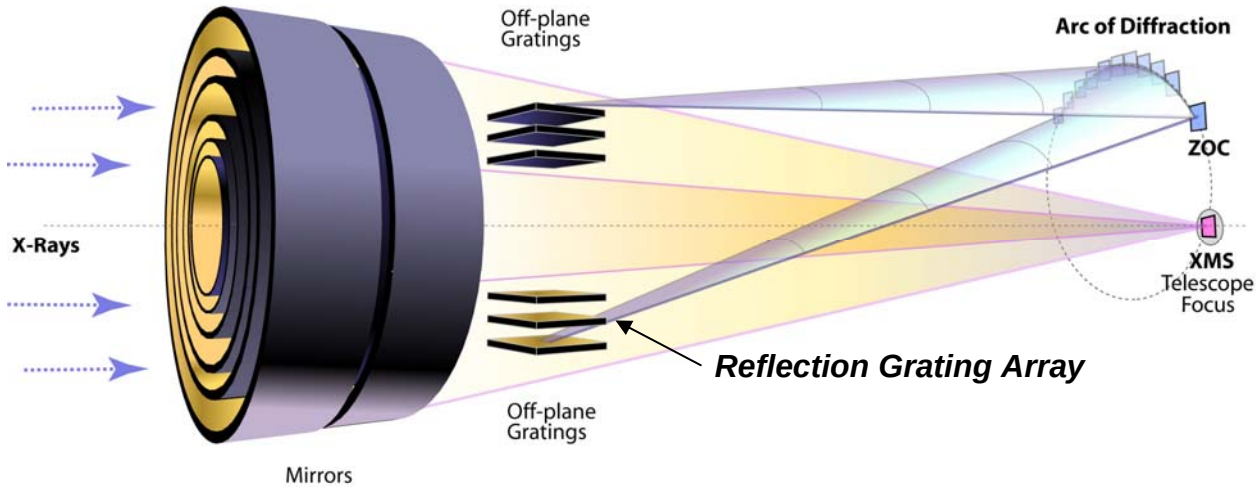
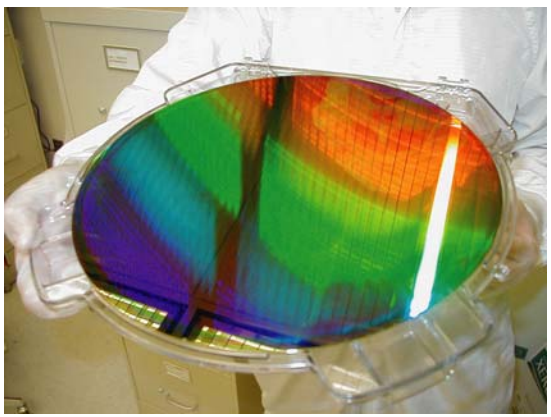
NASA Facility Science Team Meeting
Royal Sonesta Hotel
Cambridge, MA, Feb. 16, 2006

NASA *Constellation-X* Mission
Reflection Grating Spectrometer

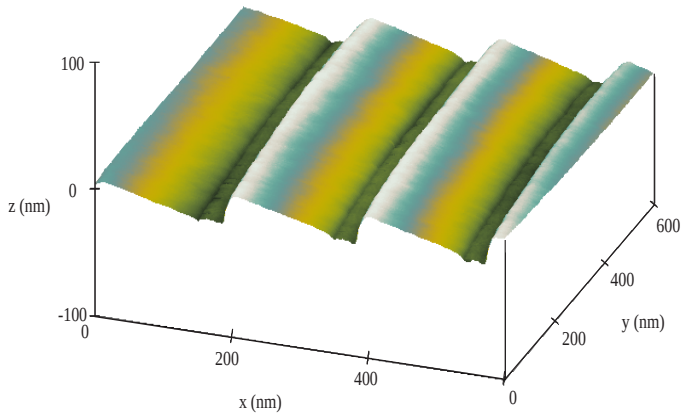


Con-X Grating Requirements

- **200 nm-period blazed gratings**
- **High x-ray diffraction efficiency**
- **Sub-nm smoothness**
- **Ultra-thin (<0.5 mm)**
- **Arcsecond flatness**
- **100 square meters**



300 mm-diameter silicon wafer patterned by MIT Nanoruler



Nanoimprint lithography results: 200 nm-period sawtooth grating

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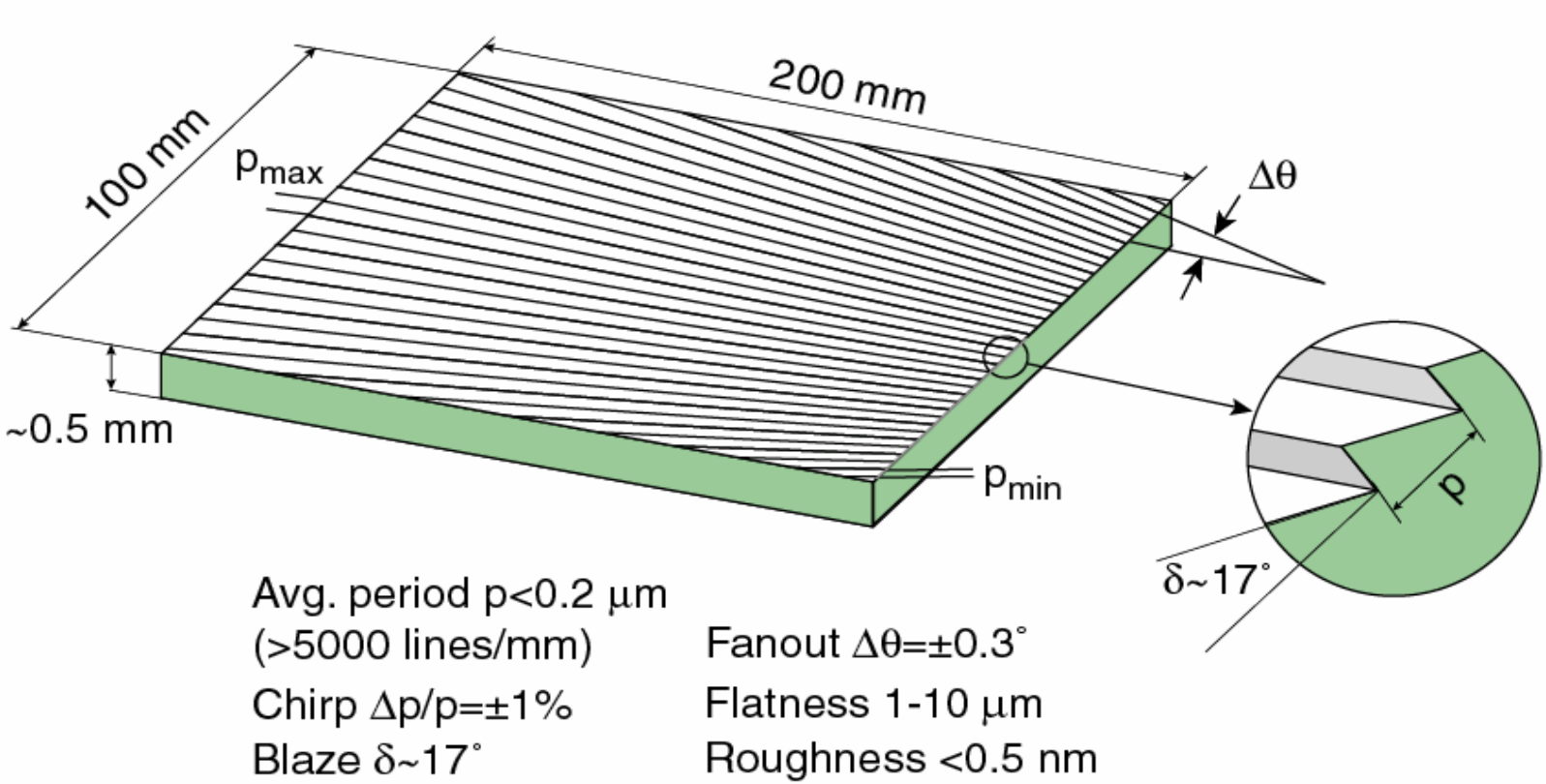
Constellation-X Grating Requirements



Avg. period p<0.2 μm (>5000 lines/mm)

Chirp Δp/p=±1%

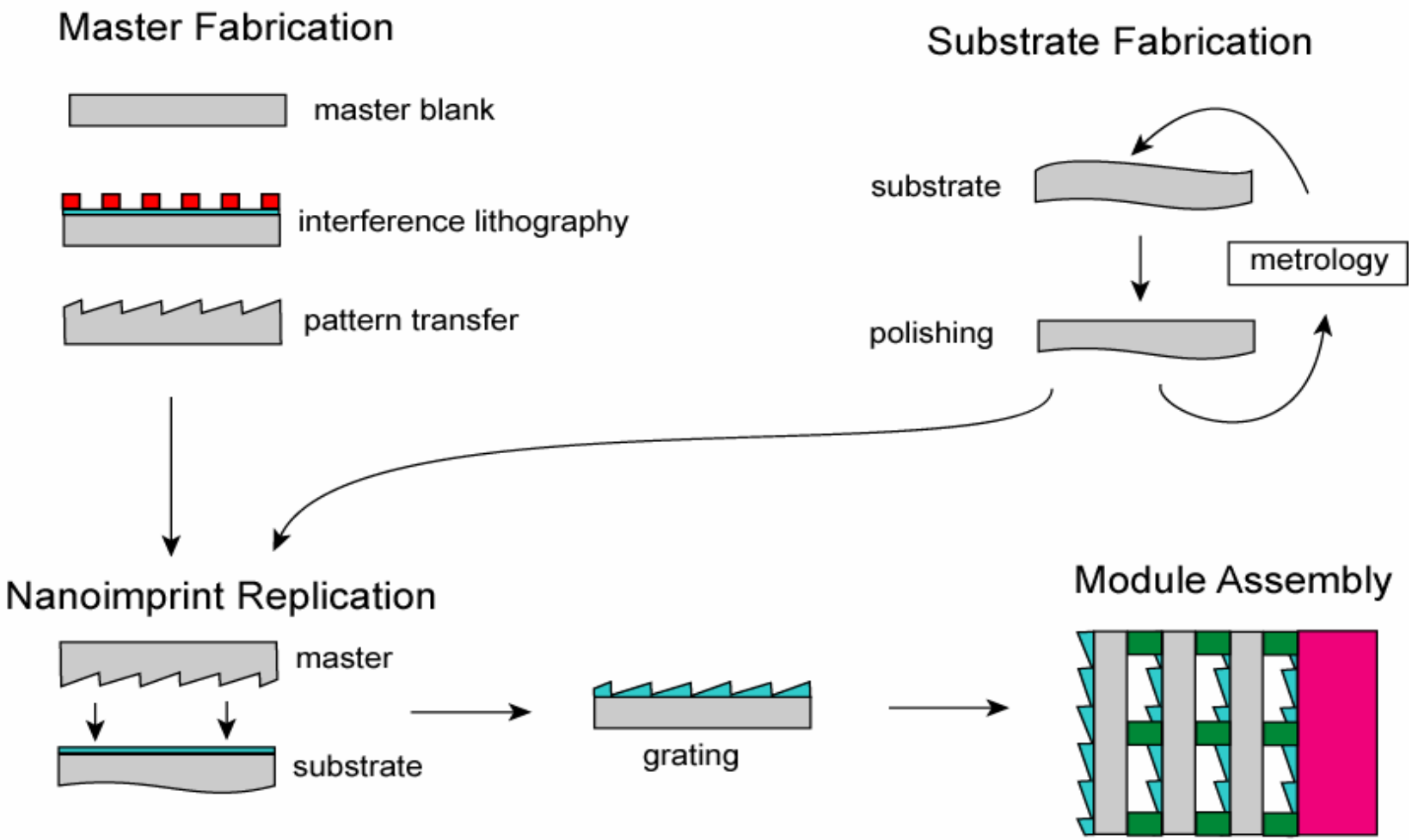
Blaze δ~17°

Fanout Δθ=±0.3°

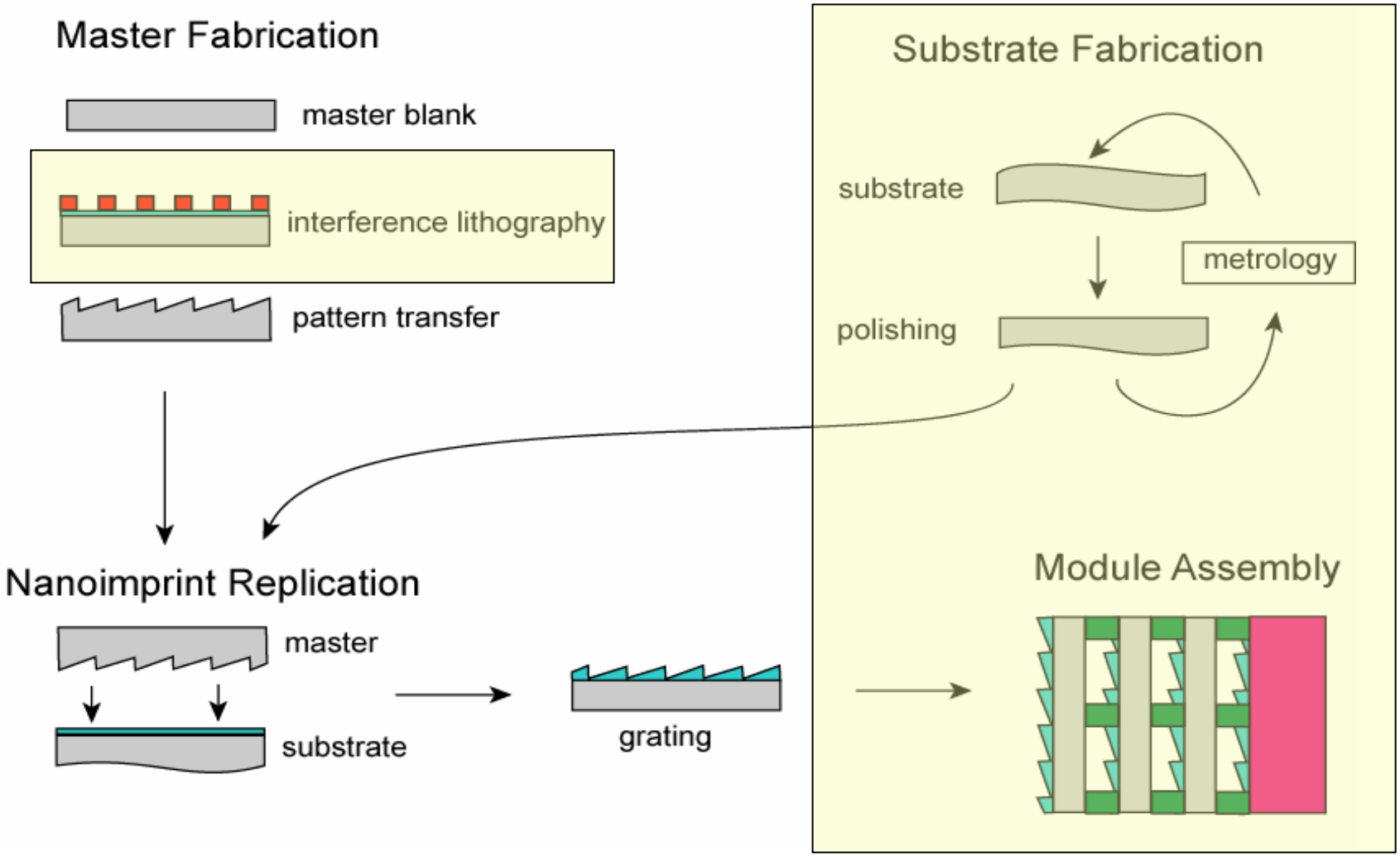
Flatness 1-10 μm

Roughness <0.5 nm

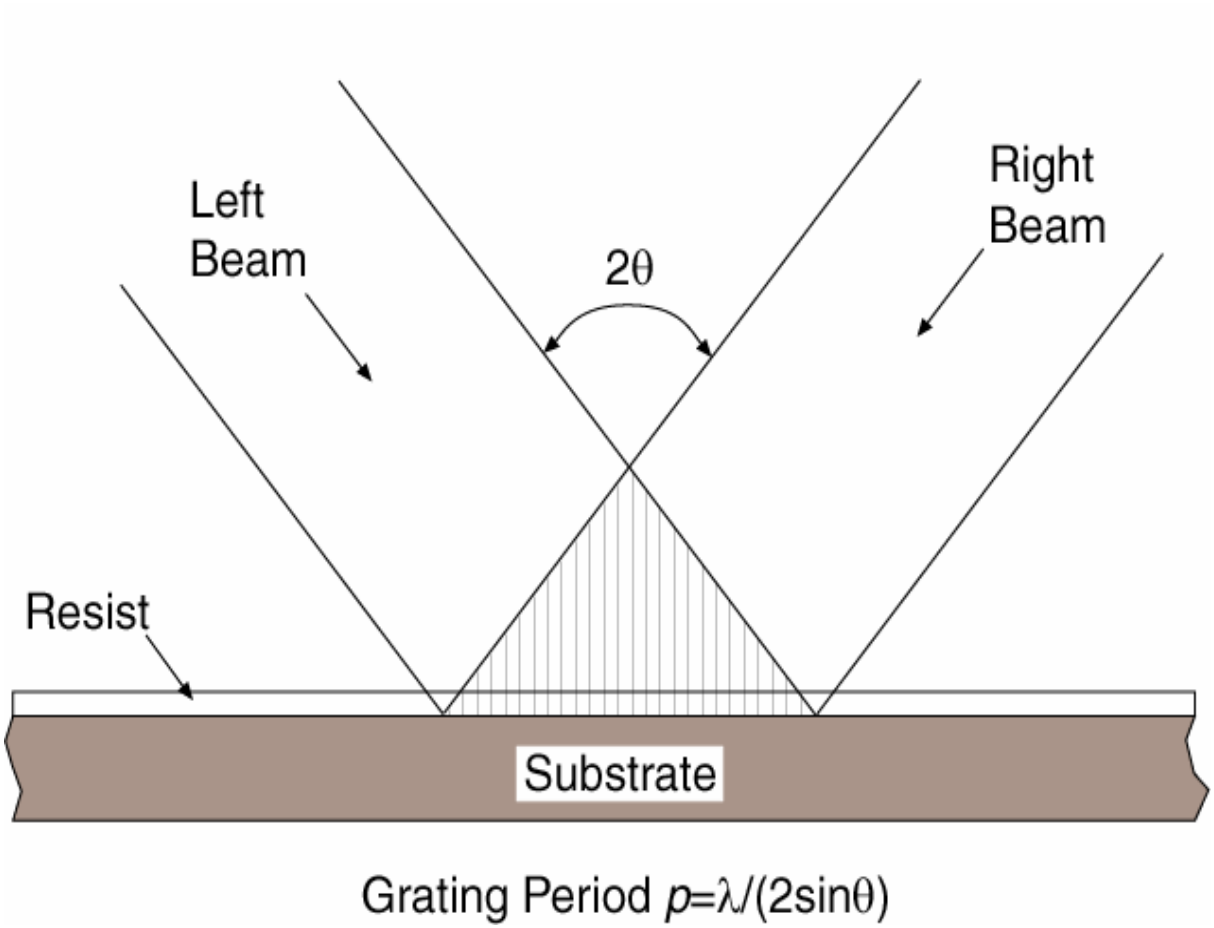
Grating Fabrication Sequence



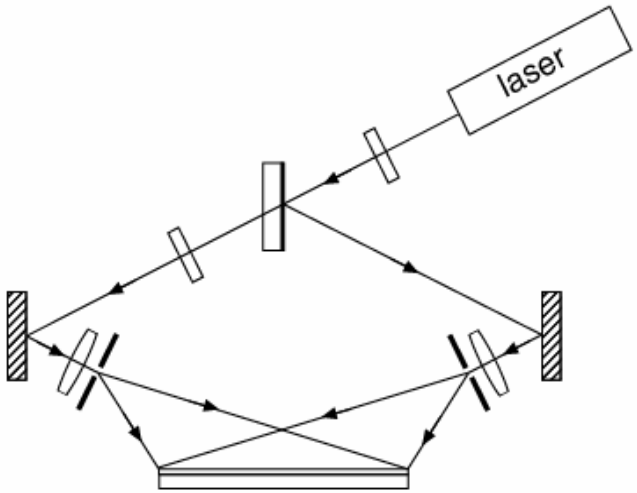
Grating Fabrication Sequence



Interference Lithography (IL)



Traditional Interference Lithography



Spherical waves cause hyperbolic phase.

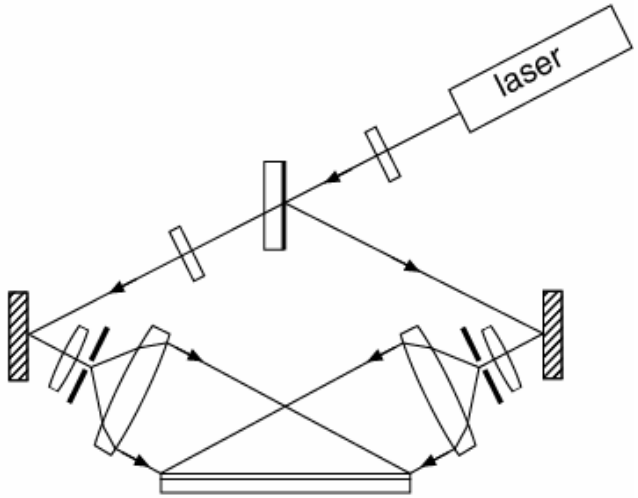
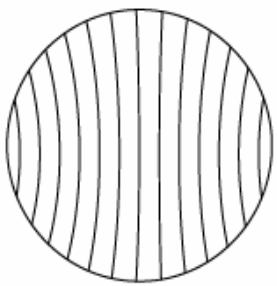
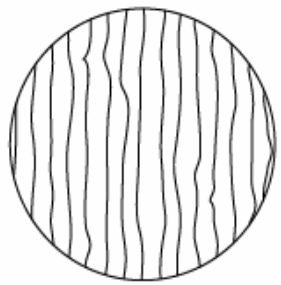


Figure errors & defects in collimating optics cause noise.

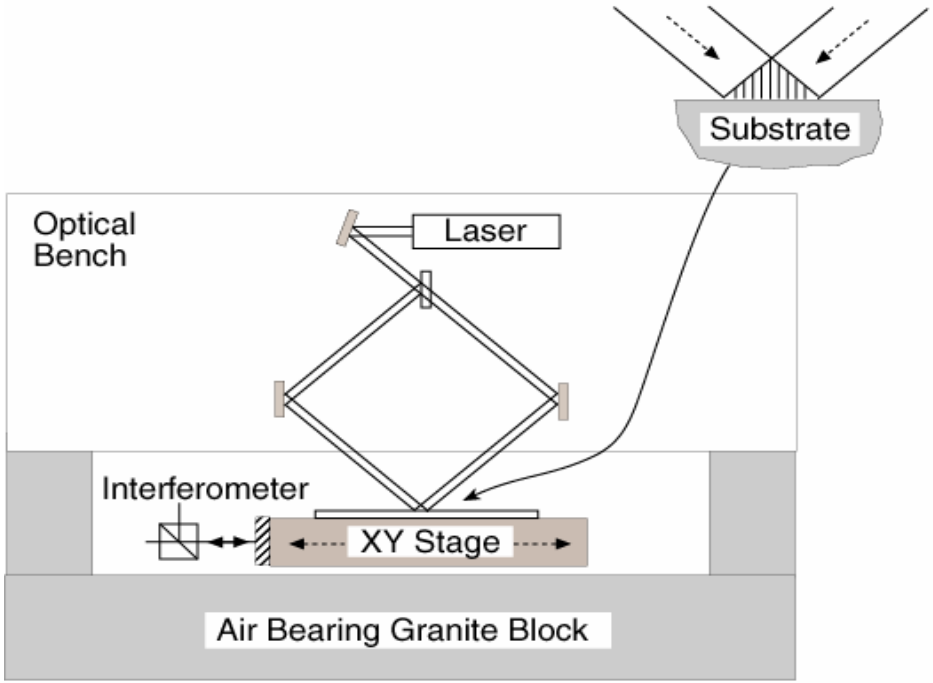


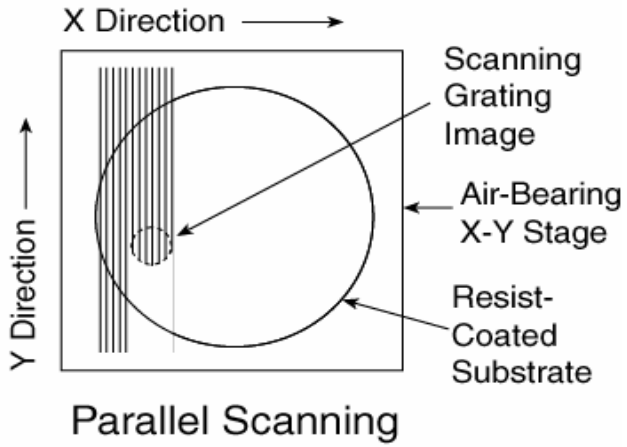
Hyperbolic Phase

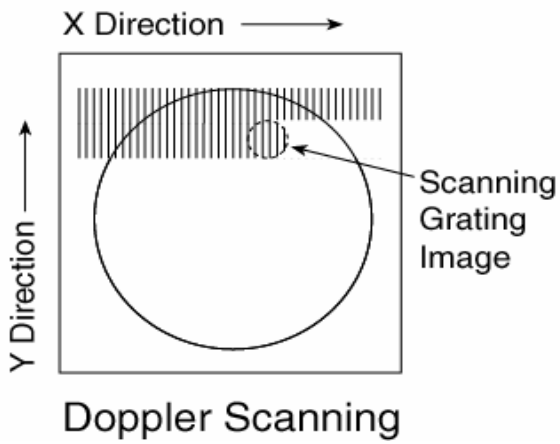


Linear Phase + Noise

Scanning-Beam Interference Lithography (SBIL)

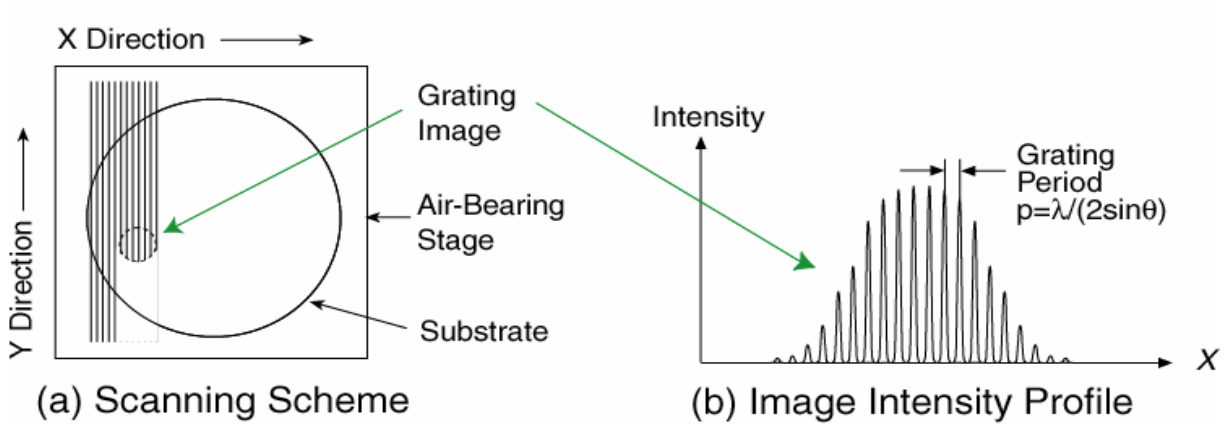


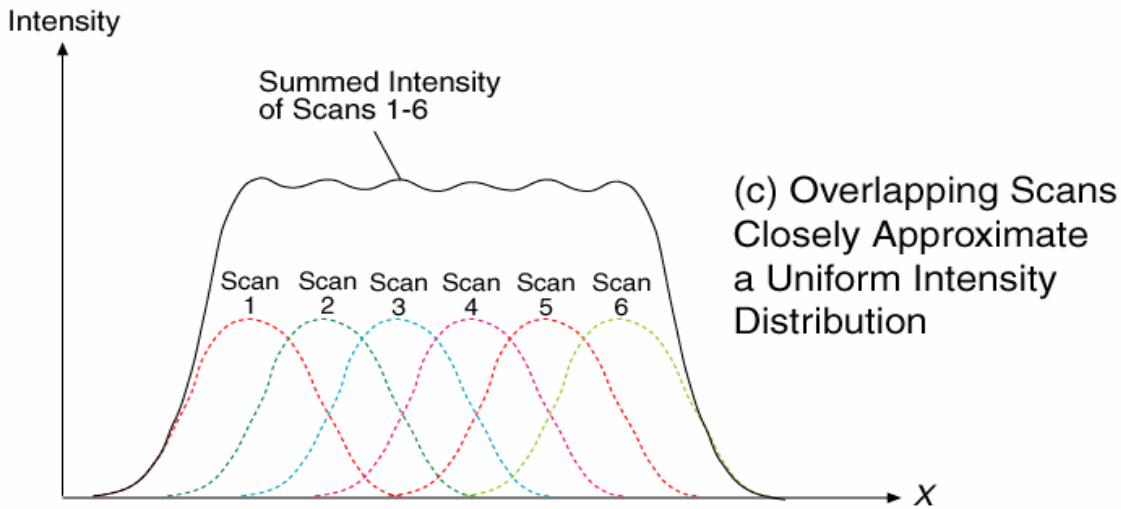




A small beam makes a small interference pattern, which is scanned.

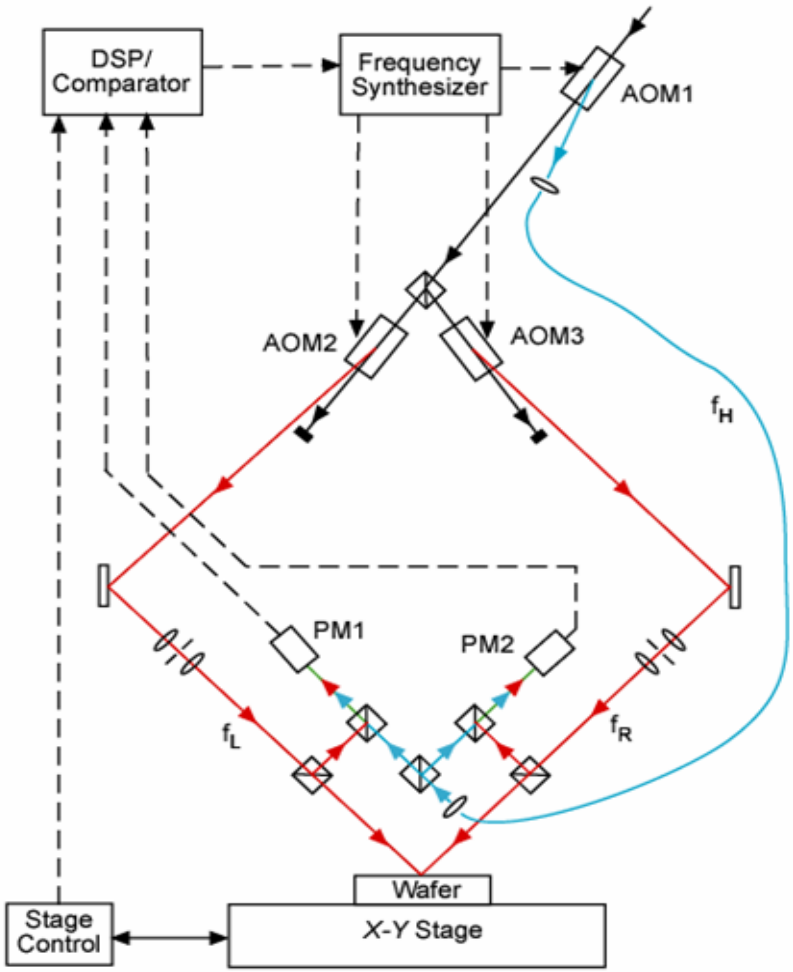
SBIL Scanning Scheme



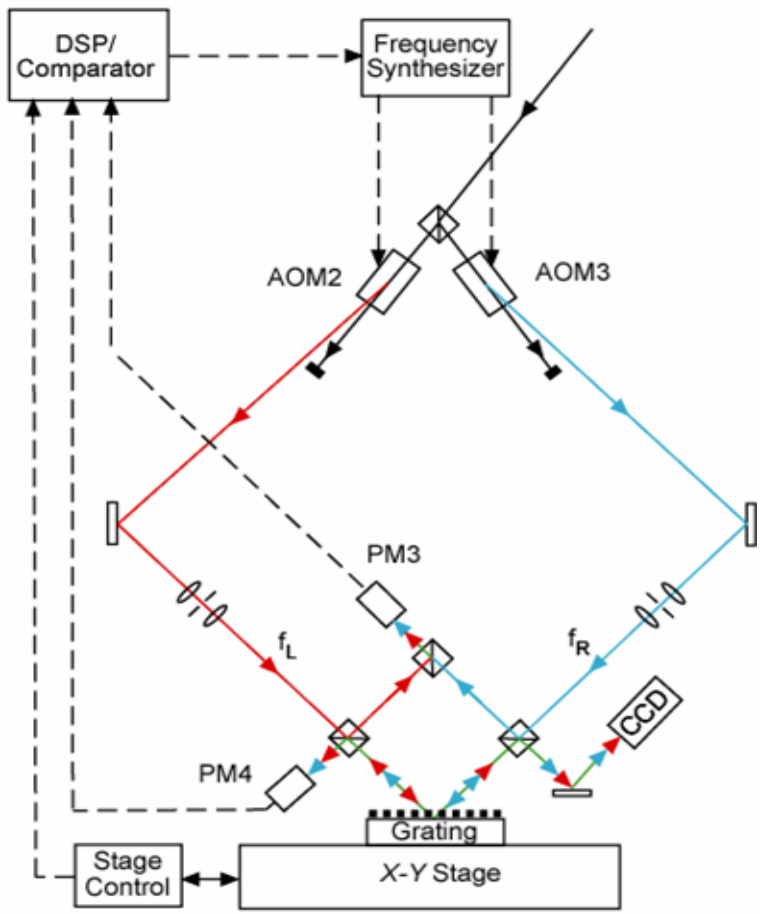


There are no boundaries between scans: they are overlapped.

SBIL Writing and Metrology Modes

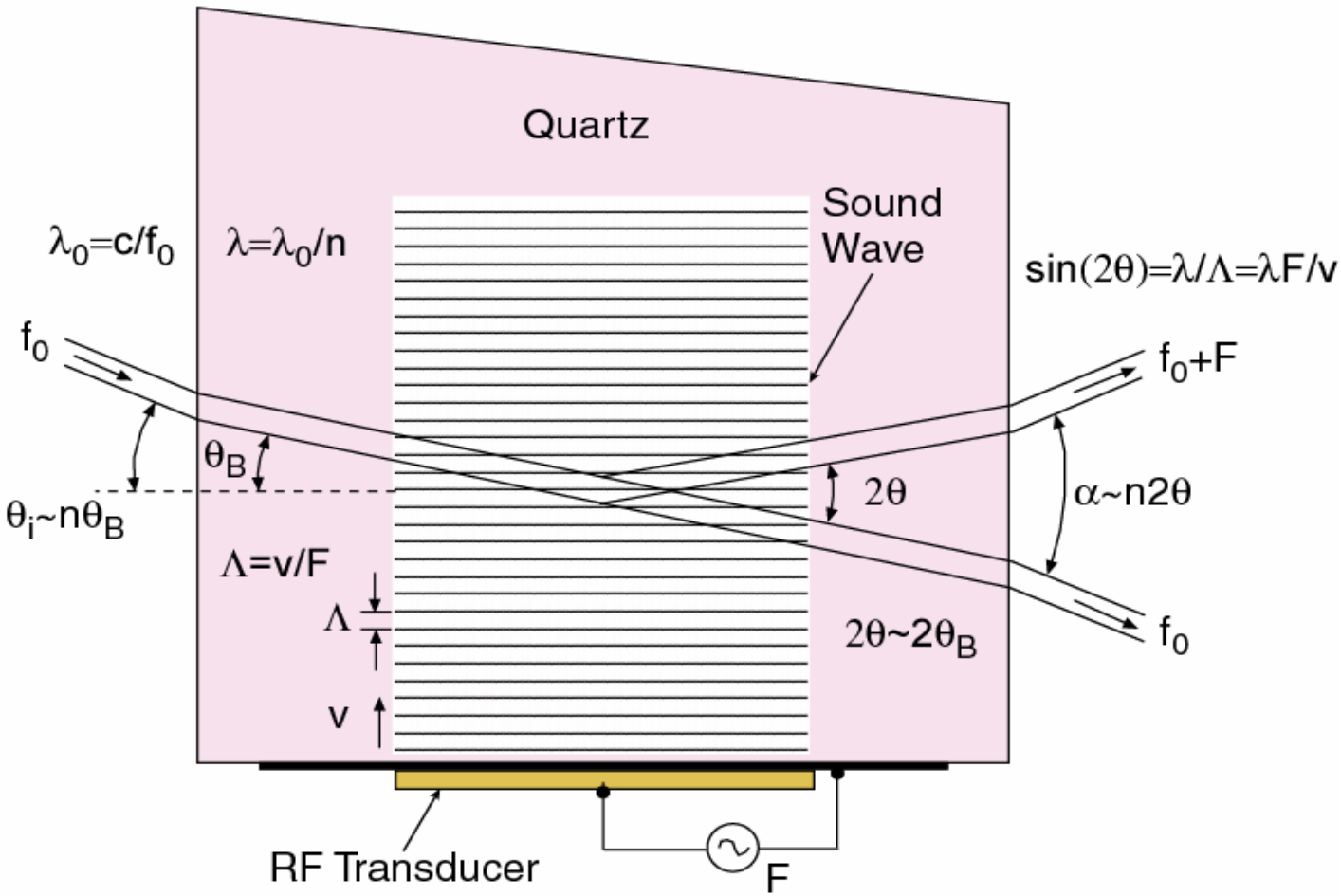


(a) Writing Mode

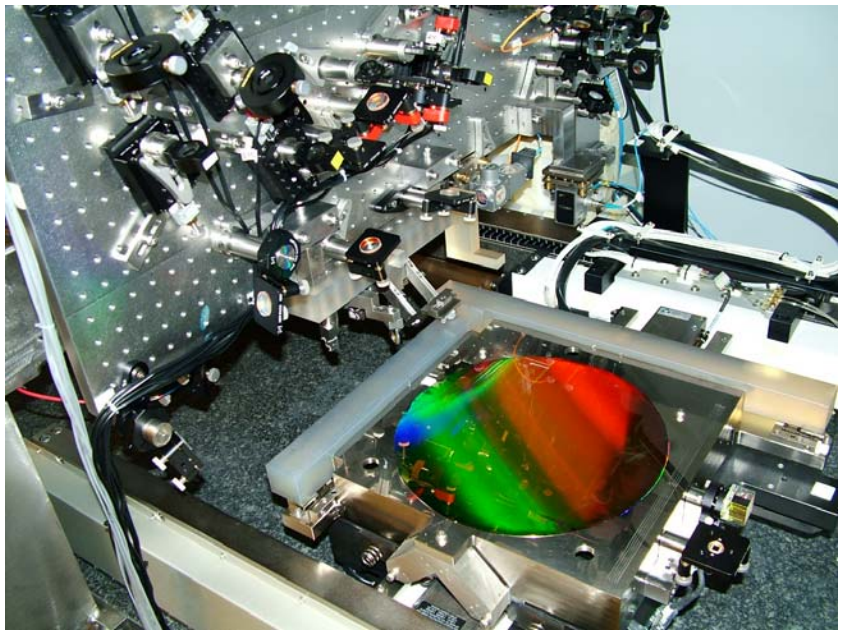


(b) Metrology Mode

Principle of Acousto-Optic Diffraction



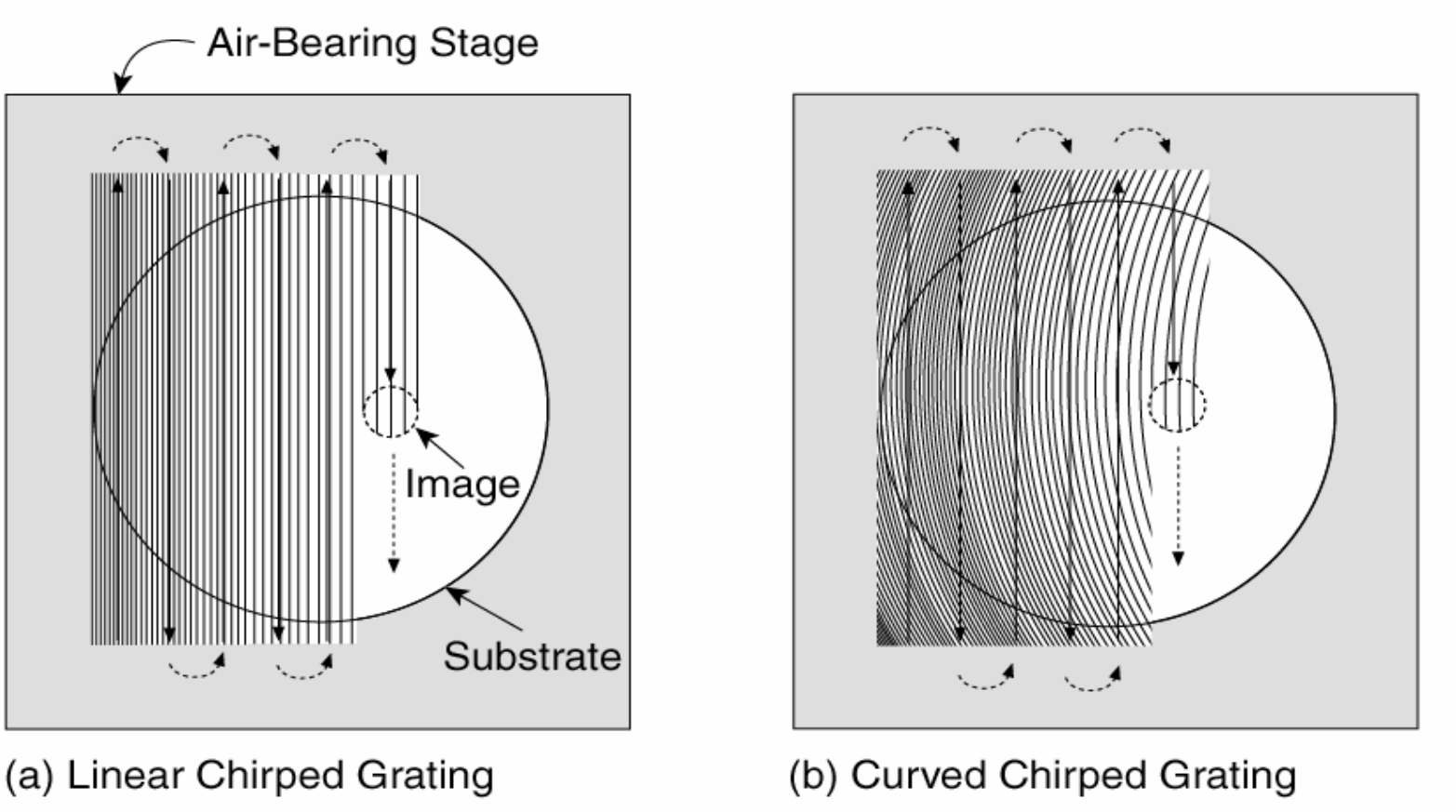
Prototype Nanoruler



Prototype Nanoruler accomplishments:

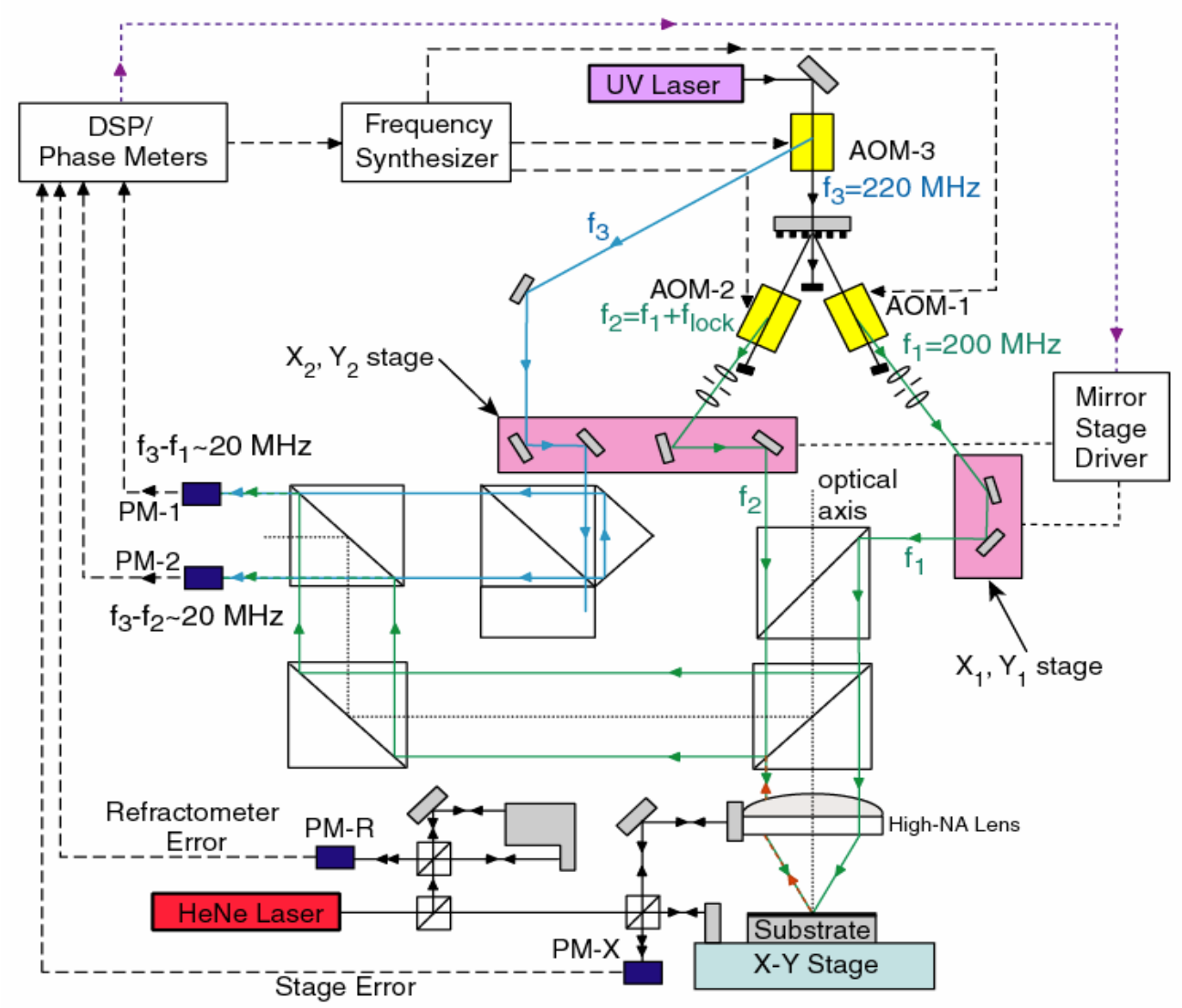
- Completed 2003
- Demonstrated SBIL concept
- Patterned gratings up to 300 mm diameter x 25 mm thick
- Platform for testing and software development
- No variable-period SBIL capability (VP-SBIL)

Writing General Periodic Patterns with SBIL

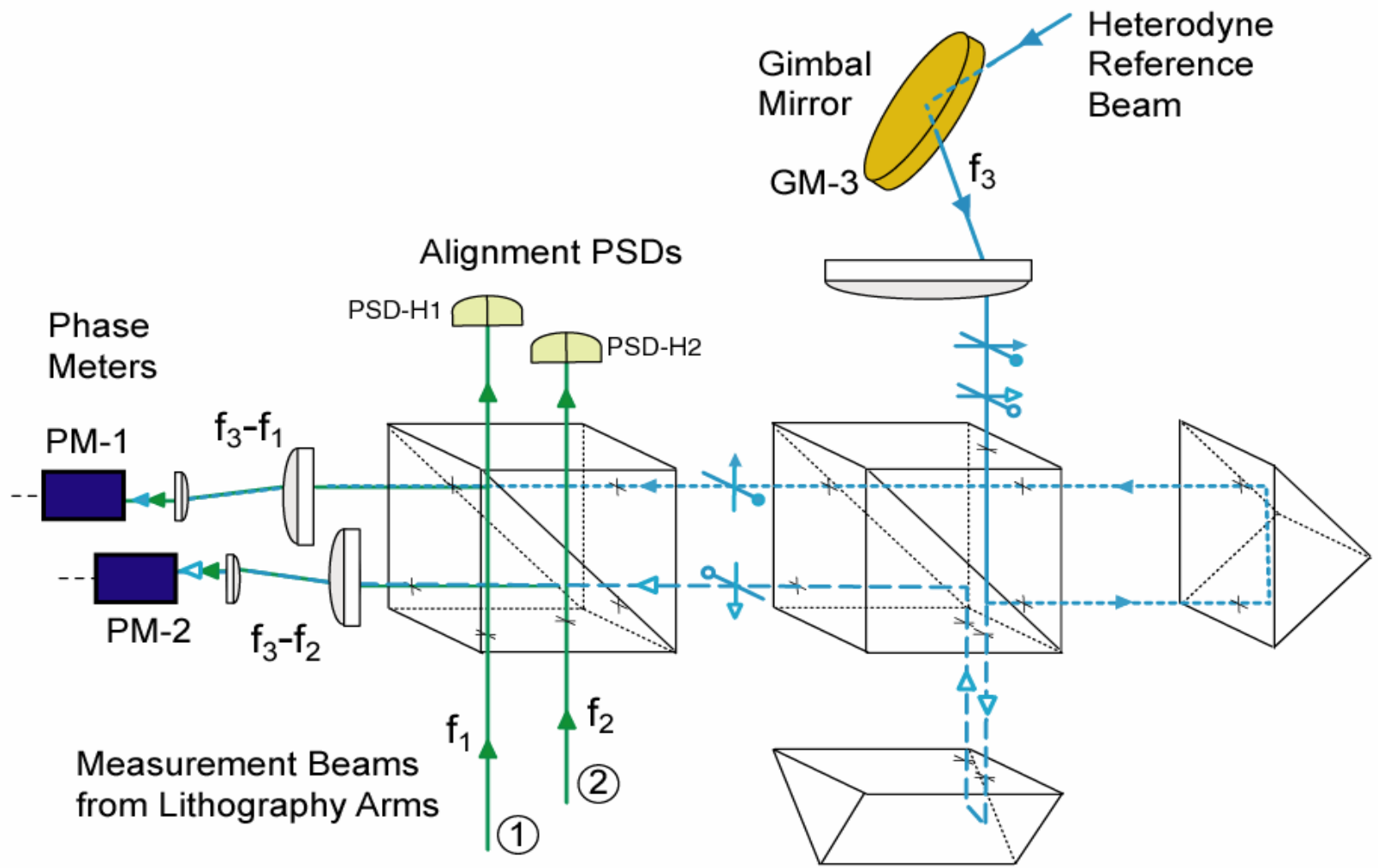


(1D chirp, 2D chirp, curved grooves, radial grooves are possible.)

Variable-Period SBIL (VP-SBIL) Concept



Rotational Shear Interferometer for Heterodyne Phase Detection



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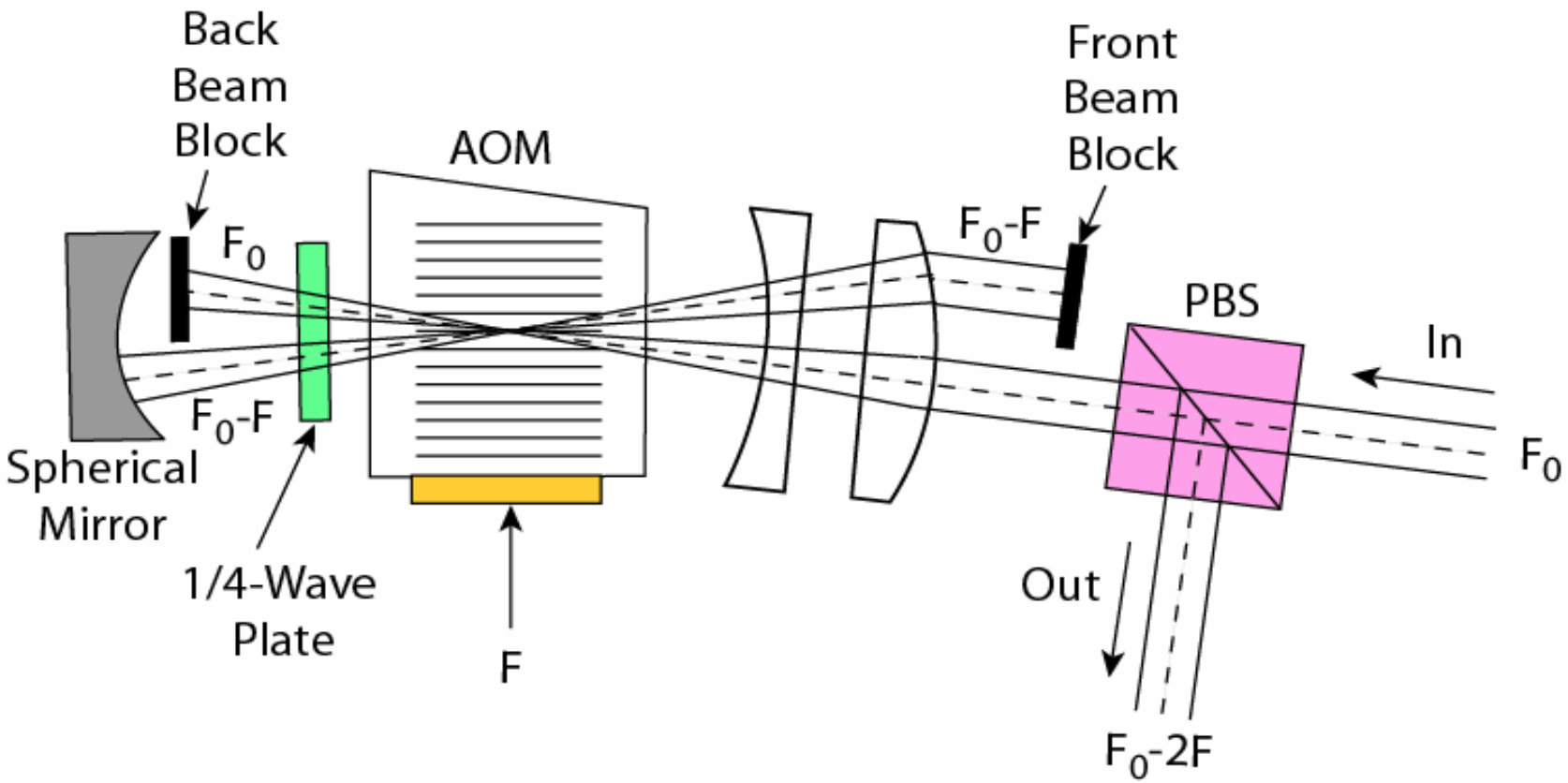
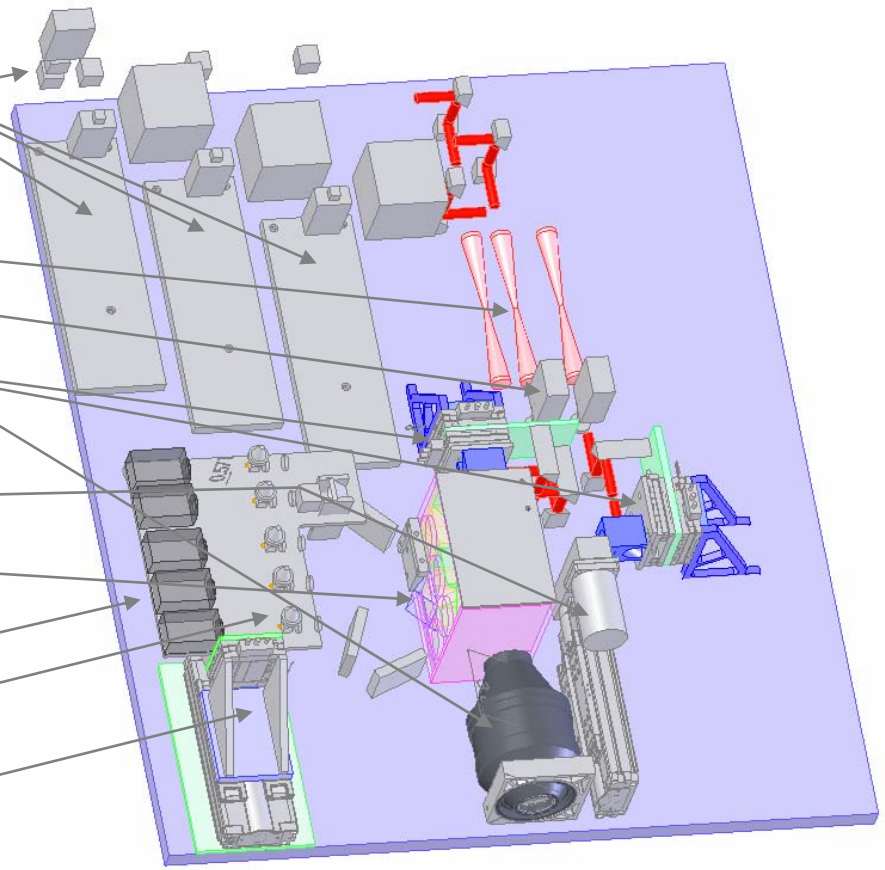
Dual-Pass Acousto-Optic Modulators



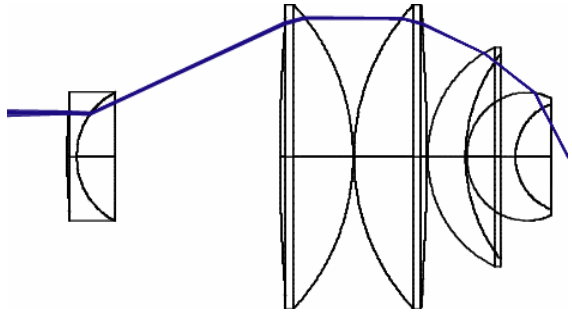
VP-SBIL Main Optical Subsystem

- Acousto-optic modulators (AOM's)
- Pre-AOM monitor
- Spatial filters
- Plane of incidence detectors
- X-Y "pupil" scanning stages
- Objective lens
  - Focus stage
- Beam switchyard ("cube farm")
- Main beam metrology
  - CMOS cameras
  - Phase meters
  - X-Y scanning stage

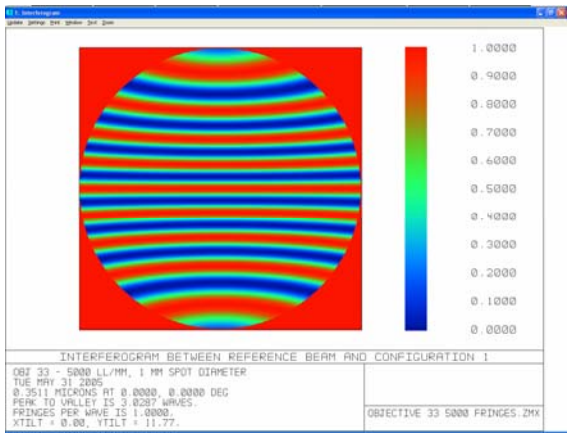


SBIL Lens Design

- Infinite-conjugate objective lens, NA=0.877
- Designed by Bauer and Associates
- Five-element, fused silica, no aspheres
- Any period from 0-5000 lines/mm (200 nm +)
- Worst-case fringe straightness <p/10 at $1/e^2$
- Super-Invar lens cell has real-time focus capability (can pattern non-flat substrates)



ZEEMAX ray trace at 5000 l/mm

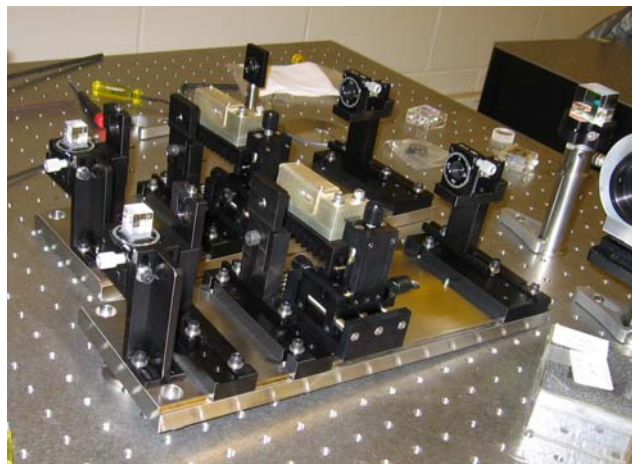


Ray trace showing fringe straightness at $1/e^4$ beam diameter

Lenses and lens cell fabrication completed

VP-SBIL Assembly and Alignment Underway

- VP-SBIL opto-mechanical system designed and built by PGL, Bauer, Fraunhofer and MIT
- Significant financial support for VP-SBIL design and hardware provided by industrial partner (PGL).
- Final alignment and integration at MIT
- All optics and major subsystems on order.
- Many key components in house and being assembled and aligned.
- Scheduled completion April 2006.



Dual-pass AOMs being aligned at MIT

Summary

- MIT Nanoruler is being upgraded to VP-SBIL capability
- Additional electronics and control software development by MIT Ph.D. students to enable real-time VP-SBIL
- Short-term goals:
  - April 2006: Upgraded Nanoruler on line
  - May 2006: Demonstrate patterning 5000 lines/mm radial-groove grating
  - Oct. 2006: Release radial-groove gratings with sawtooth profile for x-ray tests.

MIT SNL Key Personnel

Dr. Mark Schattenburg
Lab Director

Dr. Ralf Heilmann
Asst. Lab Director

Mr. Robert Fleming
Lab Manager and Engineer

Dr. Yeon-Oh Jung
Visiting Scientist

<u>Ph.D. Students:</u>
Mr. Minseung Ahn, ME
Ms. Mireille Akilian, ME
Mr. Chih-Hao Chang, ME
Mr. Juan Montoya, EECS
Mr. Yong Zhao, ME

Paul Glenn
President, Bauer and Associates
Prime contractor for VP-SBIL optical system design and fabrication.


Mark Schattenburg


Ralf Heilmann

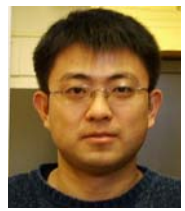

Bob Fleming


Chih Chang
ME PhD Student
VP-SBIL development, grating fabrication


Mireille Akilian
ME PhD Student
Thin substrate shaping, assembly and metrology


Juan Montoya
EECS PhD Student
Nanoruler software development


Minseung Ahn
ME PhD Student, Samsung Fellow
Grating fab research


Yong Zhao
ME PhD Student
Nanometrology research
(NSF support)


Paul Glenn

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